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THE EFFECTS OF ERRORS ON CHILDREN'S PERFORMANCE ON A CIRCLE-ELLIPSE DISCRIMINATION[1]

LAWRENCE T. STODDARD AND MURRAY SIDMAN

JOSEPH P. KENNEDY, JR., LABORATORIES FOR
RESEARCH IN MENTAL RETARDATION
MASSACHUSETTS GENERAL HOSPITAL

Children first learned by means of a teaching program to discriminate a circle from relatively flat ellipses. Children in the control group then proceeded into a program which gradually reduced the difference between the circle and the ellipses. They advanced to a finer discrimination when they made a correct choice, and reversed to an easier discrimination after making errors ("backup" procedure). The children made relatively few errors until they approached the region of their difference threshold (empirically determined under the conditions described). When they could no longer discriminate the forms, they learned other bases for responding that could be classified as specifiable error patterns. Children in the experimental group, having learned the preliminary circle-ellipse discrimination, were started at the upper end of the ellipse series, where it was impossible for them to discriminate the forms. The backup procedure returned them to an easier discrimination after they made errors. They made many errors and reversed down through the ellipse series. Eventually, most of the children reached a point in the ellipse series where they abandoned their systematic errors and began to make correct first choices; then they advanced upward through the program. All of the children advanced to ellipse sizes that were much larger than the ellipse size at the point of their furthest descent.

In a review of research on programming variables, Holland (1965) discussed a rationale for the elimination of errors in teaching programs. He wrote:

"The answer required of the subject should be one he can give if, and only if, appropriate precursory behavior has occurred." (p. 78).

"The response should be determined; thus the error rate should be low. However, the independent variable is response determination, *not* error rate . . . When errors are made in a program, not only has the appropriate precursory behavior failed to occur, but other inappropriate behavior probably has occurred, and that inappropriate behavior could be established." (p. 85).

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The progressive increase in task-difficulty, a principle often included in definitions of programmed instruction, is intended to facilitate the learner's mastery of each step of the program before he can move ahead (Skinner, 1965; Holland, 1965). The important consideration is the establishment of prerequisite behavior at each step. The present experiment proposes to show the effects of a procedure which, instead, impedes the learning of prerequisite behavior and deliberately produces errors.

Most programmed material is primarily verbal in content and for that reason is not ordinarily suitable for the quantitative specification of progressive changes in task difficulty. A program composed of nonverbal material that can be ordered along some objective continuum would provide an instrument for quantifying a subject's progress through graded levels of difficulty. We have developed a program that teaches severely retarded and other nonverbal children to discriminate a circle from relatively flat ellipses that have the same horizontal dimension as the circle. A second program tests the fineness of the discrimination each child can make. The development and validation of these programs have been described by Sidman and Stoddard (1966, 1967). In the second program, the vertical dimension of the ellipses increases from trial to trial so that they come to resemble a circle more and more closely. The degree to which the ellipses approach identity with the circle is objectively specified by the ratio of vertical to horizontal axes. Normative threshold data (unpublished), and data showing where the children make errors (Sidman and Stoddard, 1966), clearly demonstrate that the ellipse series proceeds from easy to difficult. The largest ellipse a child can distinguish from a circle is designated as his circle-ellipse difference threshold.

The threshold procedure is a variety of the classical psychophysical Method of Limits, as modified by Békésy (1947). However, the present purpose is not to describe the results of a threshold procedure as such, but to demonstrate how the procedure may be used to illuminate a basic but ill-documented principle of programmed learning. Because of its quantitatively specifiable stimulus and response properties, the threshold program is a particularly suitable instrument for examining the nature and role of errors in discrimination learning. Ordinarily, subjects proceed directly from the first program, in which they learn the circle-ellipse discrimination, into the beginning of the ellipse series. They then advance through a series of increasing ellipse sizes until they can no longer distinguish the ellipses from the circle. It is possible, however, to go from the first program directly to the end of the threshold series, thereby presenting the child with an impossible discrimination and causing him to make errors. Then, the child can approach his threshold through a series of decreasing ellipse sizes.

One procedure generates errors from the beginning; the other generates errors only when the child approaches his threshold. When the child proceeds from the easy discrimination through a series of intermediate steps to the difficult discrimination, he has the opportunity to learn the behavior that is prerequisite for the finer discriminations. When he starts with an impossible discrimination, he can only make errors. What are the effects of errors generated by requiring the child to proceed backward rather than forward along a continuous dimension of difficulty?

METHOD

Apparatus

The child worked in a well-ventilated room, approximately 5-ft square, with sound-resistant walls and door. He sat before a stimulus display and response panel composed of nine keys or screens arranged in a 3 by 3 matrix and divided by barriers. Each key was a 2 by 2-in. square of translucent plastic (Polacoat) onto which stimuli could be projected from the rear (Sidman and Stoddard, 1966). When the child pressed one of the keys, he operated a microswitch mounted behind it and delivered an electrical signal to the electronic programming circuitry and recording devices. A series of photocells behind the panel on either side of the keys determined which key was correct on each trial and governed certain other program contingencies. The stimuli to be displayed on each trial and the pattern of illumination for the photocells were photographed on Ektachrome 35 mm film and presented as a slide. Motor-driven shutters behind the keys and in front of the projector lens controlled presentation and removal of the stimuli. During this experiment, only the eight outside keys of the nine-key matrix were used; a mask covered the center key.

Procedures

When the child pressed the correct key, the shutters closed, chimes rang, and automatic devices dispensed rewards: candy-coated chocolates (M&M's) and tokens. After the session, the subject exchanged his tokens for a toy or pennies. He had been instructed about the token-exchange beforehand.

Initially, the experimenter acquainted every child with the experimental room and the reward-delivery and token-exchange system. When the first slide was presented, the experimenter told the child: "Push the key," or: "Go ahead. You can push it." The experimenter stayed with the child but gave no further help or instructions and ignored all attempts of the child to speak to him.

An intermittent reinforcement schedule began on Slide 8, so that the child obtained candies and tokens only after 50% of his correct responses. All children continued until they completed the 17-slide introductory program (see below).

Correction and backup procedures. If the child's first choice was correct, the trial ended and the slide tray advanced to present a new slide. The position of the correct key changed from trial to trial. When the child pressed a wrong key nothing happened; he had to correct his error. Therefore, every trial had to end with a correct key-press. Then, if the child had made one or more errors on that trial, the slide tray backed up instead of advancing, and presented the preceding slide to the child again. In a program which builds progressively, the backup, after the child has corrected an error, returns him to an easier step which he had already mastered. Also, when the program has failed to teach the child what to do next, he will be unable to advance beyond the stage where he had difficulty (Holland, 1961). The backup procedure was not used if the child made an error on the first slide of a series. This prevented the tray from reversing into the preceding series of slides, or, in the case of the first slide in the tray, prevented disengagement of the tray from the projector.

The teaching programs. The program to teach the preliminary circle-ellipse discrimination was a 17-slide series. It began simply by requiring the child to choose the one bright key from seven dark keys, a response usually easy to establish. The correct key contained a circle on a bright yellow background. Through the next six slides, the illumination gradually increased on the seven dark keys. By Slide 7, the child had to select the key with a form (circle) on it from seven equally bright keys with no form. On Slide 8, very faint ellipses were introduced on the seven incorrect keys. During Slides 9 to 17 the ellipses gradually became more distinct. On Slide 17, the criterion slide, the child had to base his discrimination on the difference between the forms. The program teaches the circle-ellipse discrimination, almost without failure, to normal children as young as 2.5 yr of age and to severely retarded older children (Sidman and Stoddard, 1966, 1967).

The threshold program began on Slide 18; since that slide began the circle-ellipse threshold series, no backup was permitted if the child made an error on that slide. Starting with Slide 19, the vertical height of the ellipses increased in very small steps. Figure 1 schematically illustrates the threshold series. The circle, which is the same throughout, is not shown. Its diameter is equal to the major axis of the ellipses. All seven ellipses on each individual slide are the same, and the ratios of their minor to major axes are shown along with the slide numbers on which they appear. Each of the first five ellipse sizes appears on only one slide because no subject 3 yr of age or older has demonstrated a threshold below that level. Beginning with the 0.74 ellipse, each ellipse size appears on two consecutive slides. The ellipse size increases more gradually at the higher ratios, when finer discriminations are required. No individual has successfully distinguished the largest ellipse, 0.985, from a circle. The criterion for determining an individual's circle-ellipse difference threshold is the largest ellipse beyond which he is unable to advance. Since there are eight keys, an individual's first choice will be correct by chance on two successive trials only once in 64 occasions.

Control subjects. When a child completed the circle-ellipse discrimination program and reached Slide 18, he continued without interruption into the threshold series. He continued until he met a criterion of at least one error on five consecutive presentations of the same slide, or, in rare cases, until he asked to stop.

Experimental subjects. When a child in the experimental group reached Slide 18 successfully, the session was interrupted briefly while the projector tray was advanced to Slide 44, the final slide in the ellipse series. Because the forms were indiscriminable from each other at that stage, the child inevitably made errors.

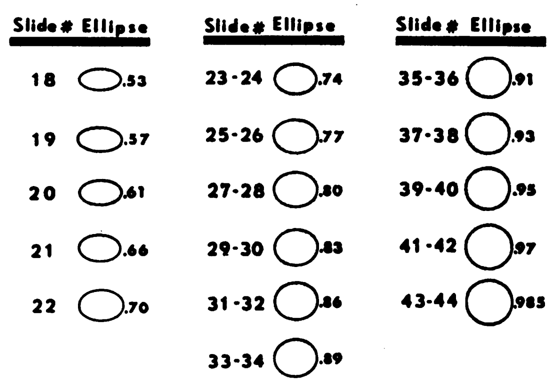

Fig. 1. Schematic illustration of the ellipse threshold series. The ellipses and the ratio of their minor to major axes are shown beside the numbers of the slides on which they appear. The major axes were 1 in. and the ellipses are reduced here to scale.

The backup condition provided that he would proceed backward through the slide series until he began to make correct first choices. The usual criterion for ending a session, at least one error on five consecutive presentations of the same slide, remained in effect.

An additional group of children repeated the backward progression several times, never fewer than four. The error criterion for each run was three, instead of five, consecutive incorrect trials on the same slide. This allowed more trials before the child tired or became satiated. After each run, the slide tray was put back to Slide 44, and the session was restarted. All runs occurred within a single session.

Subjects

The children had been temporarily hospitalized for general medical reasons and were considered neurologically and behaviorally normal by their physicians. The single exception (A.S., in the control group) was a patient in a state school for the retarded. Twelve children of the experimental group performed once on the reversed threshold series; four additional children had repeated backward runs. The ages of the 16 children are given in conjunction with their data; they ranged from 3 yr, 10 months (3-10) to 10 yr and 11 months (10-11). The eight children in the control group performed on the threshold program in the usual forward direction. These control subjects were the last four children in the normative series to provide threshold data before the period of this experiment and the first four children afterward. Their ages ranged from 2-3 to 9-11.

RESULTS

Control Group

In the initial phase, all the children successfully completed the brightness-fading and ellipse-fading programs. In learning the circle-ellipse discrimination, before starting the threshold series, the eight control children made 0, 0, 1, 2, 2, 4, 7, and 8 errors; no child made errors on more than five trials or on more than five slides.

Figure 2 shows the progress of the eight control subjects through the threshold program. The figure also illustrates how the data were recorded. The recording paper moved at a constant speed from right to left. The recording pen was attached by a chain and pulley system directly to the slide tray in the projector. When the subject's first choice on a given trial was correct, the slide tray advanced and pulled the pen up the paper. Each step upward on the records indicates the child's successful progress through that portion of the program. When the child made an error, the recording pen made a diagonal mark and the slide did not change; when he eventually pressed the correct key, the slide tray reversed, and the recording pen stepped downward.

Beginning with Slide 18, marked on each record by the slide number, each child progressed with few or no errors through the beginning of the threshold series. The slide number above the high point on each child's record represents his furthest advance into the threshold program, except for A.S. and K.R.P. These two children eventually advanced one ellipse-size higher, but the records have been ended at this point to condense the figure.

The continuous progression of the ellipse series, and the help provided the children by the backup to an easier step, permitted them to learn to discriminate ever finer differences between the forms, in a relatively continuous manner, until they closely approached their eventual threshold. This finding is the central feature of the control data and contrasts markedly with the results of the experimental procedure.

Experimental Group

Descending Sequence: Single Runs

Like the control subjects, all 16 children who went backwards through the threshold program had first completed the 17 slides of the circle-ellipse discrimination program. In learning initially to discriminate the circle from relatively flat ellipses, eight of the children made no errors and three made only one error. The remaining five children made 4, 5, 5, 9, and 10 errors; no child made errors on more than three slides or on more than four trials.

Data showing single backward progressions of six children are presented in Fig. 3. Each record starts with Slide 44. Striking features of these records are the numerous errors per trial and the almost continuous series of reversals well back into the ellipse series. The lowest

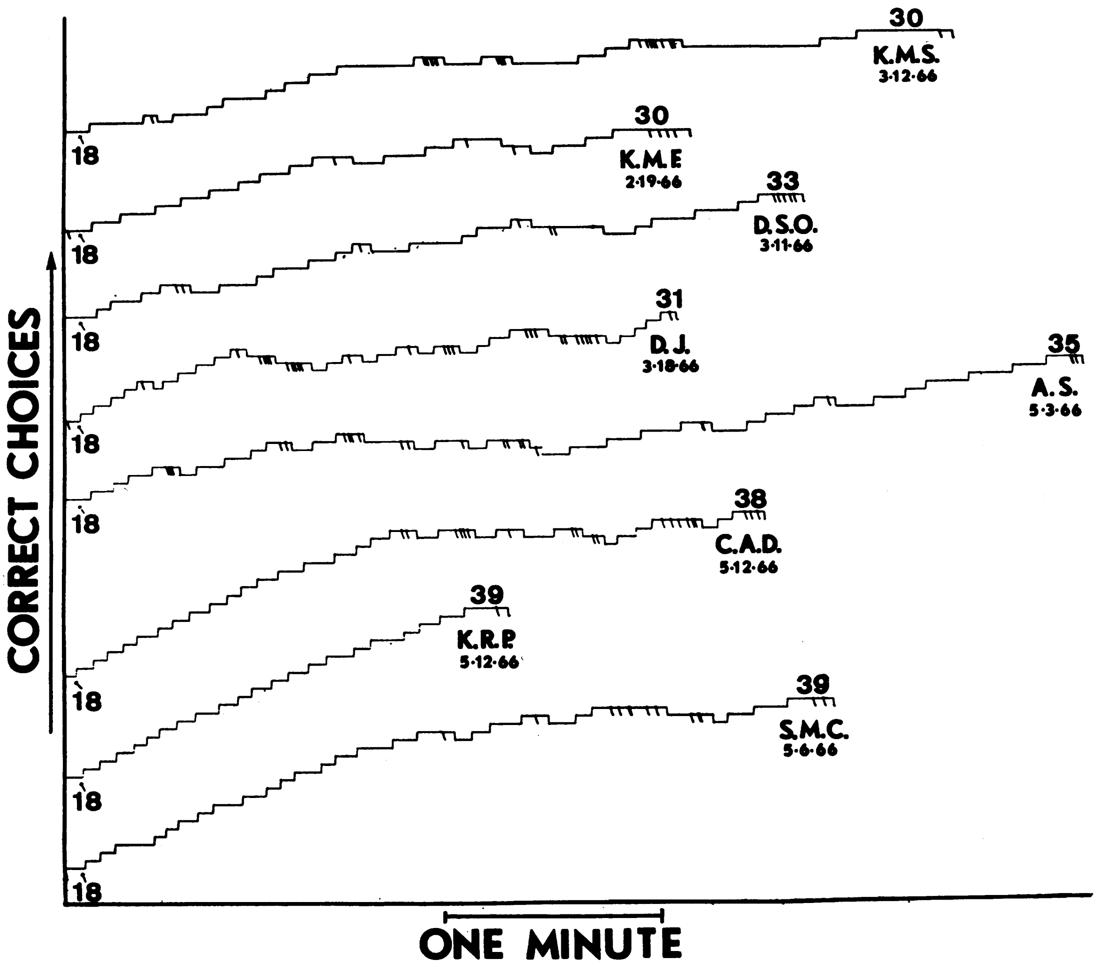

Fig. 2. Trial-by-trial performance of the eight control subjects on the circle-ellipse threshold program. Below the end of each curve are the child's initials and the date of his session. Slide numbers identify the initial slide (18) and the highest slide reached by each child. Diagonal "pips" show incorrect choices. Each upward step indicates an initial correct choice; each downward step indicates a correct choice after errors. The children's ages were: K.M.S., 2-3 (years-months); K.M.F., 2-4; D.S.O., 4-8; D.J., 5-7; A.S., 9-3; C.A.D., 9-4; K.R.P., 9-10; and S.M.C., 9-11.

slide reached by each child is indicated below the record by its number, enclosed in an ellipse that has the same axis ratio as the ellipses on that slide.

After reaching their lowest point, the children began to make correct first choices and then advanced through the threshold series. The bottom record shows that M.J.C. met the error criterion before he began to make correct first choices. The highest slide each child reached after starting his upward climb is numbered at the end of each record, again within the ellipse that appeared on that slide. (P.X.D. and C.A.M. eventually advanced to larger ellipse sizes, but the portion of their records shown here illustrates the major finding.) To facilitate comparison, the final slide is also numbered where the child first encountered it during his downward progression.

The main effect of the backward progression, demonstrated uniformly by these children, was to produce errors. As a consequence of the errors, the subjects reversed through the program. They continued to make errors and backed down to an ellipse size well below the circle-ellipse threshold which they later achieved. When the children eventually began to advance successfully through the ellipse series, their errors were not followed by a second continuous reversal downwards

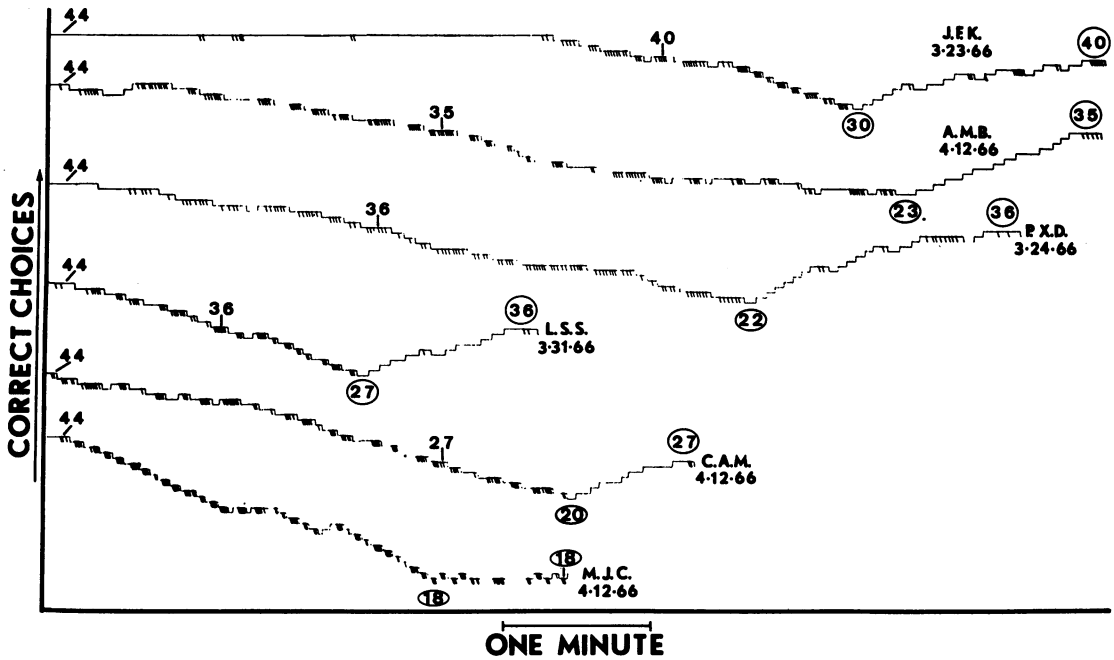

Fig. 3. Trial-by-trial performance of six subjects on the reversed circle-ellipse threshold program. The child's initials and his session-date follow each record. Slide numbers identify the initial slide (44), the lowest slide to which each child reversed, the highest slide of his subsequent advance, and the same highest slide where the child first encountered it during the downward progression. The lowest and highest slide are each enclosed in an ellipse with the same axis ratio as the ellipses on that slide. Diagonal "pips" indicate incorrect choices. The children's ages were: J.F.K., 7-7 (years-months); A.M.B., 9-2; P.X.D., 9-4; L.S.S., 5-2; C.A.M., 5-6; and M.J.C., 6-7.

through the series. M.J.C., who never began to make correct first choices, had previously demonstrated that he could discriminate the ellipse size on Slide 18 from a circle.

The records of Fig. 4 represent the three children who made the most errors and took the longest time in their initial descent through the program. Each record begins at Slide 44. Because of their length, the records have been cut into segments which are placed one below the other for compactness of presentation. Each segment begins at the left. Two of the children reversed all the way back to Slide 18, at the beginning of the series, and the third reversed back to Slide 22. Eventually, all three children began to respond correctly and advanced successfully past slides on which they had previously made errors. Slide numbers identify both the point of furthest advance and the same slide during the initial descent. (W.A.S. and R.A.C. went on to demonstrate circle-ellipse thresholds one ellipse-size larger than that indicated in the records.) Like the children in Fig. 3, when these children made errors during their ascent, the errors tended to be isolated and did not initiate a long series of reversals.

The record of L.A.S. in Fig. 5 has been divided into segments like those in Fig. 4; however, slide numbers are shown on the ordinate. The record begins on Slide 44. The child's errors resulted in the typical descent through the ellipse series until she reached Slide 23, on which she always made a correct first choice. She met the error criterion on Slide 24. The session was interrupted and the child was restarted on Slide 18 (at *a*) to see if the larger circle-ellipse difference would help her to start responding correctly. When she continued to make errors, the session was interrupted again and she was then restarted on Slide 8 (at *b*), the first slide of the ellipse-fading series. At this point, she had only to discriminate a key with a form from equally bright keys with no apparent forms. The return to this easier task reestablished errorless responding. She did not make her first error during her ascent until Slide 29, well into

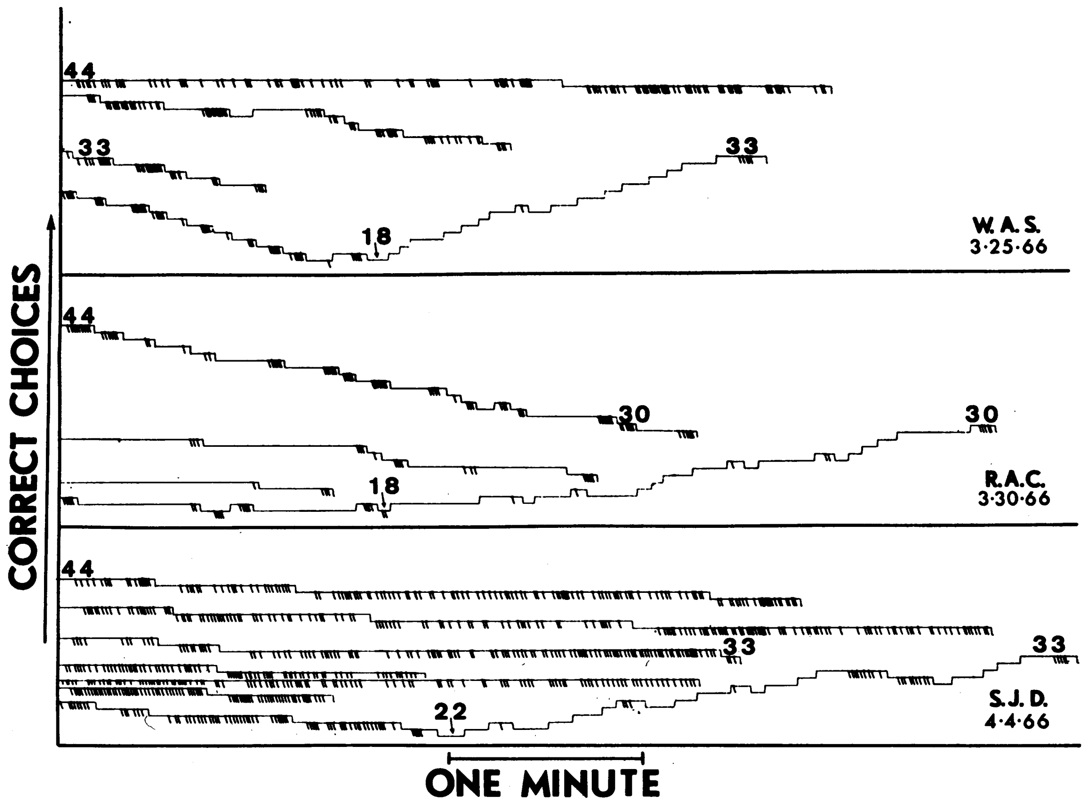

Fig. 4. Trial-by-trial performance of three children on the reversed circle-ellipse threshold program. The child's initials and his session-date identify each record. The curves have been cut into segments and each segment begins at the left. Slide numbers identify the initial slide (44), the lowest slide to which each child reversed, the highest slide of his subsequent advance, and the highest slide where it was first encountered during the downward progression. The children's ages were: W.A.S., 7-0 (years-months); R.A.C., 4-7; and S.J.D., 5-5.

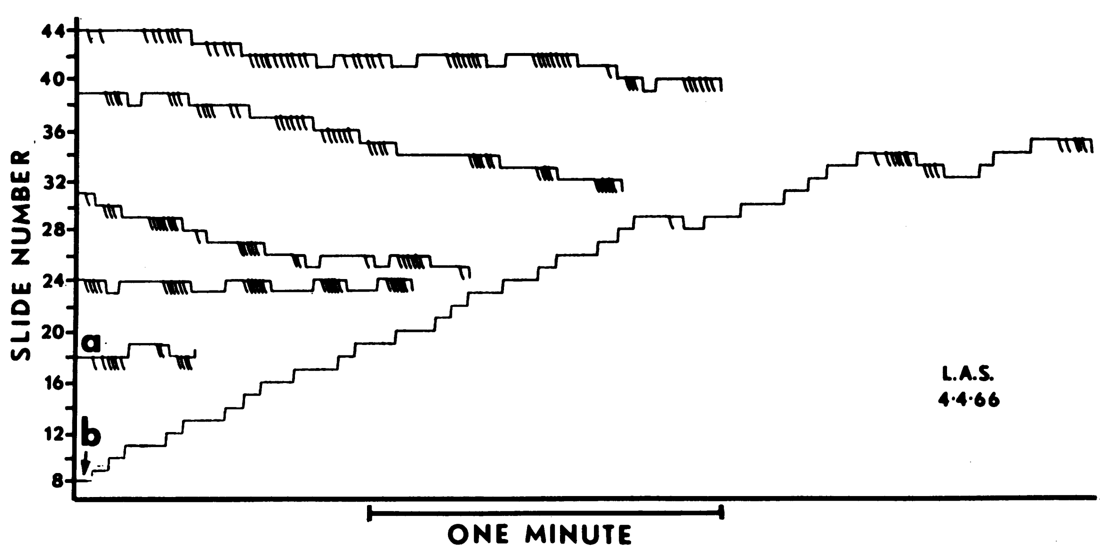

Fig. 5. Trial-by-trial performance of L.A.S. (age 6-7) on the reversed circle-ellipse threshold program. As in Fig. 4, the record has been cut into segments and each segment begins at the left. The first segment starts at Slide 44. At Slide 23, the session was interrupted, restarted at Slide 18 (a), interrupted again, and restarted at Slide 8 (b).

the ellipse series, and she then advanced with little difficulty to Slide 35. (She eventually advanced through Slide 40.)

When L.A.S. backed down through the program, her errors were not random. She responded in a systematic manner, by circling around the key matrix (the eight keys formed the perimeter of a square). However, she usually began each circling sequence by pressing the key adjacent to the one that had been correct on the preceding trial. On Slide 23, the correct key was adjacent to the key that was correct on Slide 24. Therefore, when she backed up from Slide 24 her first choice on Slide 23 was correct, and she advanced to Slide 24 again. On Slide 24 she again circled the keys until she came to the correct one. After the backup to Slide 23, she again correctly chose the key adjacent to the previous correct one. She repeated this pattern five times and met the error criterion. Her correct responses on Slide 23, therefore, were unrelated to the circle-ellipse discrimination. The same error pattern accounts for all her other correct first choices during her descent, except for those on Slide 41. After her successful ascent to Slide 35, which approached the limits of her capacity to discriminate circles from ellipses, the same error pattern reappeared.

Circling was the predominant error pattern shown by eight of the 10 children whose records appear in Fig. 3, 4, and 5. Some of the eight children, instead of simply pressing each adjacent key once in turn, sometimes pressed each key several times before moving on to the next adjacent one. A variant on circling shown by one child (M.J.C. in Fig. 3) was to press all the keys in each row from left to right. This child pressed the upper left key as her first choice consistently. The usual point of departure for circling by the other children of these eight was either the key that had been correct on the previous trial or an adjacent key.

The control-group subjects developed similar error patterns, but only after they approached ellipse sizes that represented their circle-ellipse threshold.

Descending Sequence: Repeated Runs

The data of the four subjects given repeated runs on the descending sequence are shown schematically in Fig. 6. The curves show only a trial-by-trial record of advances and reversals; error marks have been omitted and there is no time axis. As in Fig. 5, slide numbers are on the vertical axis. Each curve stops at the slide which represents the child's furthest advance on that run and the curves are numbered consecutively. All children had at least four runs and J.M.G. had five. Each run was continued until the child met the abbreviated error criterion of three consecutive incorrect trials on a given slide, but the criterion trials are not included in the figure.

The first run of all these children resembled in every respect the first-run records shown in Fig. 3 to 5. The children's errors caused them to reverse far past ellipse sizes which they later showed they could discriminate from a circle. They did not back up as far on subsequent runs. On the third run of J.A. and M.J.M., and the fifth of J.M.G., these children reversed to a point only slightly below their eventual threshold. They learned to stop making systematic errors, and instead, to attend to the differences between the forms as soon as they reached ellipses near their thresholds.

The additional practice in observing the forms helped J.A. and J.M.G. to learn to discriminate finer differences, but the performance of three of the children (J.A., M.J.M., and R.M.), eventually deteriorated below previous higher levels.

The errors made by the children who had multiple backward runs were like the errors made by the single-run subjects, and fell into specifiable patterns.

DISCUSSION

When the threshold program is presented as a continuous progression from easy to difficult circle-ellipse discriminations, the child learns to discriminate ever finer differences between the forms. The program provides the opportunity for the child to learn appropriate prerequisite behavior. When the ellipses are relatively flat, he may be attending to one or more features of the stimuli that are difficult to distinguish when the ellipses are larger. For example, to distinguish ellipses that more closely resemble a circle, he may have to transfer the basis for his discrimination from height or area to more subtle differences in curvature. Without the gradual program, the children do not accomplish this transfer, and even stop

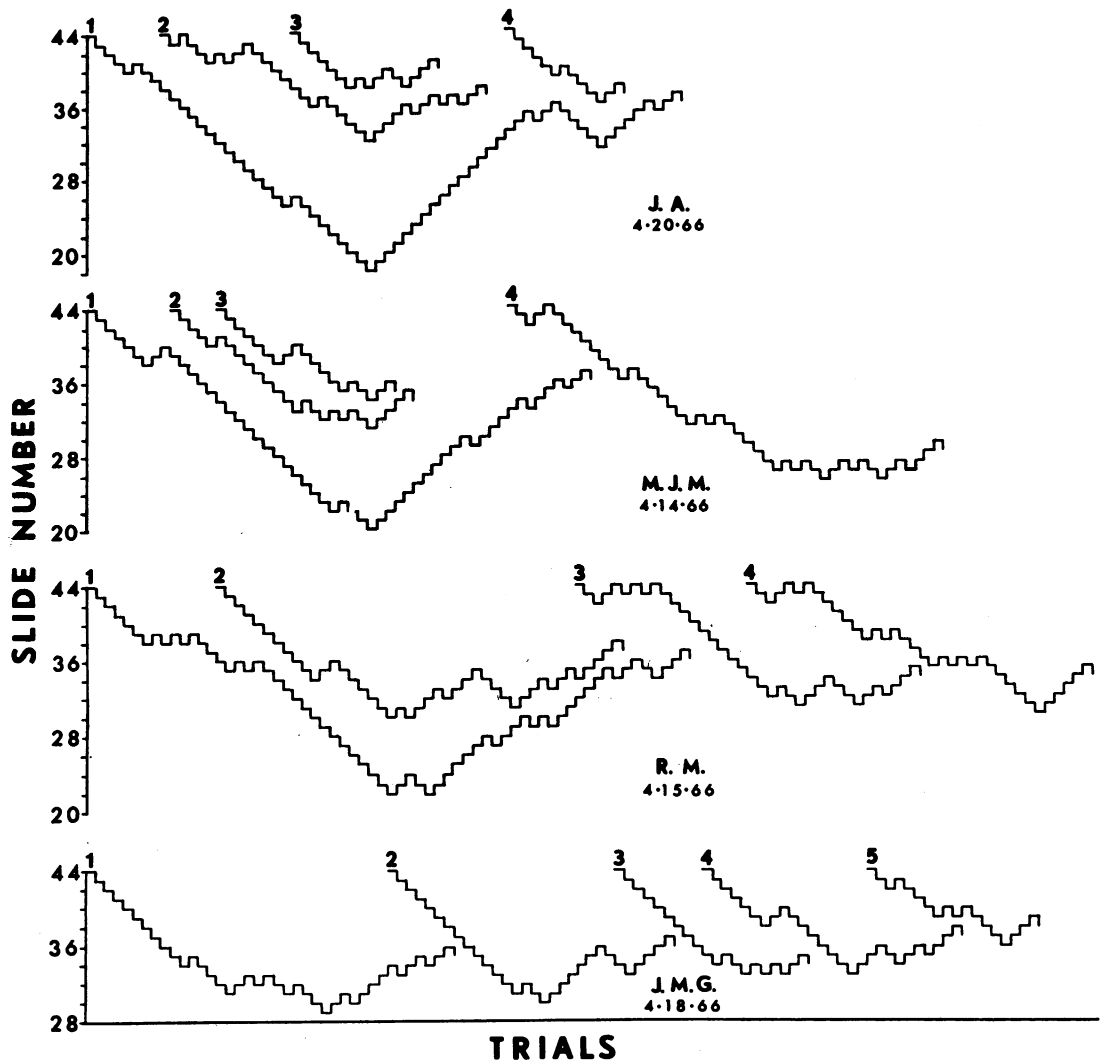

Fig. 6. Trial-by-trial performances of four subjects who repeated the reversed circle-ellipse threshold program. The curves schematically record only advances and reversals; error marks are omitted and there is no time axis. Each curve begins at the left and they are numbered consecutively. Each curve stops at the furthest advance by the child on that run, after his initial descent. The children's ages were: J.A., 9-2; M.J.M., 7-1; R.M., 9-1; and J.M.G., 4-7.

observing relevant aspects of the forms until the difference between circle and ellipse greatly exceeds their threshold.

When the children in the experimental group were presented with the final slide in the ellipse program, they clearly lacked the prerequisite behavior necessary for them to respond correctly. Instead, they learned inappropriate error patterns. The errors were not random and could usually be traced to reinforcing contingencies in the procedure and apparatus (Sidman and Stoddard, 1967). Circling the key matrix, the predominant error pattern, eventually enabled the child to reach the correct key; if he responded rapidly, his frequency of reinforcement remained relatively high. The children did not attend to the circle and ellipses as a basis for making a choice until the difference between the forms became much larger than their eventual difference threshold. The gap between the ellipse size to which each child reversed and the ellipse size to which he eventually advanced is a quantitative measure of the effect produced by this procedure.

A commonplace observation in psychophysical experiments is that the ascending and descending Method of Limits yield discrepant threshold values. The children in this experiment who started with the impossible discrimination did not begin to respond correctly until they reached an ellipse size below the region of their eventual threshold. This finding is only superficially analogous to the classical psychophysical observation.

Subjects in psychophysical experiments are practiced until they become "well-trained observers," and their ascending and descending threshold discrepancy is small. In the present experiment, the psychophysical finding might have been replicated in those children who had repeated experience with the procedure. After varying amounts of practice, three of these children stopped making errors (circling) and began to observe the forms again when they had reversed only slightly below their demonstrated thresholds (Fig. 6). They had become "well-trained observers." (The long time required to achieve this result, and the risk of losing children as subjects do not recommend the backward progression as a technique for measuring thresholds in children.) The children's descent through the ellipse series during their initial run was of an entirely different order of magnitude. Its greatest relevance to the area of psychophysics is that it makes explicit the learning phenomenon responsible for the rejection of threshold data when they are obtained from unpracticed subjects.

The data of M.J.C. (Fig. 3) and L.A.S. (Fig. 5) show that a child who has learned inappropriate behavior patterns may not recover the performance that the program is designed to teach; the backup to the largest circle-ellipse difference at the beginning of the series did not help these children attend to the forms. The circle-ellipse discrimination had to be retaught to L.A.S.; presumably the same procedure would have been successful with M.J.C. since she had previously mastered the ellipse-fading program.

A related effect is that the backward progression can create reinforcing conditions that are not adequate to maintain the children's behavior. Two children in the experimental group, whose data were not shown, asked to stop before they began making correct first choices. One of the children reversed back to Slide 26 in the ellipse series and the other to Slide 39; both children made many errors per trial. They were 3 yr old, younger than any of the other subjects. The deterioration in the performance of several of the children who had multiple exposures to the backward procedure is a similar effect.

The backward progression probably did not produce a decrement in the children's difference threshold. All 13 children who provided measurable data obtained thresholds well within the limits of the normative data obtained from children of comparable ages (Stoddard and Sidman, unpublished data).

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